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PREDICTION OF VEHICLE INTERIOR NOISE USING FRF BASED SUBSTRUCTURING AND TRANSFER PATH ANALYSIS

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Abstract

The FRF based substructuring method and the transfer path analysis were applied to the prediction of operational interior noise in passenger vehicle system. The FBS method is widely applied to product development in various fields since this method can predict the response of the whole system when a part of the system is changed. Especially, the FBS method is very useful to predict the vehicle dynamic properties in case of changing some parts of the vehicle. Target parts can be established on the basis of experimental models and FE models of the prototype constructed in the planning stage of car development. This paper focused on the application of the FBS method to predict vehicle dynamic properties. First, the test based FBS method was applied to vehicle body and subframe. Then the experimental model was replaced with FE model to apply the hybrid FBS method. When the FBS method was applied, the connection property of substructures was considered. The vibro-acoustic transfer function was predicted with hybrid FBS model. This predicted vibro-acoustic transfer functions were applied to experimental TPA to predict operational interior noise in vehicle system.

INTRODUCTION

According to the development of the numerical analysis technique, an analysis of complicated structures such as ships, cars, airplanes became possible. However accurate modelling of those complicated structures is not easy because it is difficult to model connecting parts between substructures. Namely, it is not easy to construct complicated models with only numerical approach, while simple structures are not. The techniques dealing with this type of problems are usually referred to as substructure synthesis. The coupling method is categorized into two groups, one group uses modal data and the other group uses the measured response data (Frequency Response Function) [1, 3]. Ren [4] introduced GRC method (Generalized Receptance

Coupling method) which uses the measured FRF data. In this paper, the research was performed using GRC method and the coupling equations were processed using commercially available software. Finally operational interior noise is predicted using hybrid FBS results.

FFR BASED SUBSTRUCTURING

FRF based substructuring method predicts the dynamic properties of an assembly using information of a each component dynamic properties. When substructures are coupled, force equilibrium and compatibility conditions are satisfied. And the connection properties of a joint should be considered on the substructure interface.

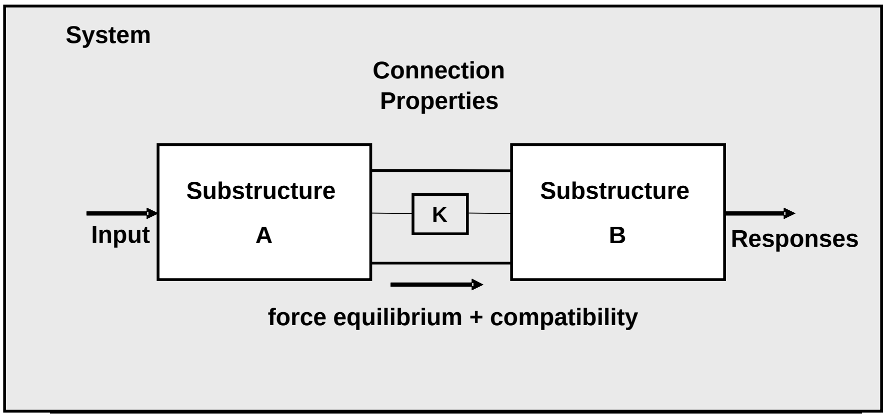

Figure 1 – Simple outline of FRF Based Substructuring

APPLICATION OF FBS METHOD TO VEHICLE SYSTEM

We determined the target part as subframe in vehicle system. Subframe is the part that supports power train system which is the primary source of vehicle NVH. The subframe is connected with engine at two points, and with vehicle body at six points. Then the subframe is the most important part that the vibration of power train system is transferred. Actually subframe is the part which is optimized to reduce the vibration which is transferred from engine with many experiments and design modifications.

Construction of Experimental FBS Model

Before constructing hybrid FBS model, each substructure was constructed with FRF data from experiment and the noise transfer function was predicted. The construction of experimental FBS model is pre-process of construction of hybrid FBS model. Finite element model was constructed on the base of this experimental model.

The experiment was executed with trimmed body of the vehicle. Body and acoustic cavity were defined as substructure A, and subframe as substructure B. Figure

2 and Figure 3 shows vehicle body and cavity (substructure A) and subframe (substructure B) each. Circled points are coupling points with substructure A and squared point is input point which replace engine excitation force as hammer input force in Figure 3.

Figure 2 − Substructure A : vehicle body and cavity

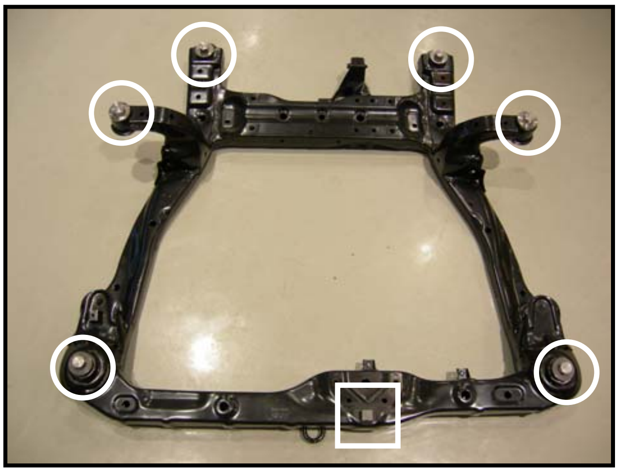

Figure 3 − Substructure B : subframe

In order to apply coupling equations, free-free component frequency response functions of each substructures were measured at the coupling points. At Substructure A, 3-axial acceleration signals are measured at six connecting points and one acoustic signal is measured at the response point in the vehicle cavity. 18x18 size acceleration FRF matrix and 18x1 size acoustic FRF matrix were constructed. At substructure B, 18x18 matrix was constructed with acceleration signals at six connecting points. Exciting front roll mount (input point) and measuring at six connecting points, 18x3 matrix was constructed. Vibro-acoustic frequency response functions in assembly were predicted by applying test based FBS method which using measured FRF data.

Construction of Hybrid FBS Model

After synthesizing substructures with experimental model, experimental subframe model was replaced with FE model to make hybrid FBS model. The subframe FE model was analyzed and correlated with experimental subframe model. Table 1 shows the correlation between experimental subframe modes and FE subframe modes. Some modes which don't exist in experiment appear. The important point of hybrid FBS method process is the correlation of experimental subframe model and FE model. The good correlation results insure the reasonable prediction of subframe dynamic properties after FE model modified. The correlation result shows not so good quality. To improve consistence of results, more accurate correlation of experimental model and FE model is needed [2]. The correlation process was performed with experimental modal analysis of subframe. Correlated FE subframe model was replaced with experimental subframe model and applied the hybrid FBS method using FE subframe model and experimental body model to predict vibro-acoustic frequency response functions in assembly.

Table 1. Correlation between experimental subframe modes and FE subframe modes

Mode No.	Experimental Mode (Hz)	FE Mode (Hz)	Difference	
			Hz	%
1	56	57	1	1.75
2	96	100	4	4.00
3	144	142	2	1.41
4		145		
5	156	156	0	0.00
6	193	190	3	1.58
7	214	200	14	7.00
8	233	235	2	0.85
9	251	260	9	3.46
10		285		
11	296	287	9	3.14
12	351	340	11	3.24
13	396	370	26	7.03
14	432	448	16	3.57
15	505	498	7	1.41

Connection property

The body and subframe is connected using rubber bushes. The dynamic stiffness of rubber bush was measured with limited frequency range and the rest of the values were estimated by extrapolation method. For calculating FBS synthesized results with 1 Hz interval, the dynamic stiffness which measured with 5 Hz interval were estimated with 1Hz interval by interpolation method. Figure 4 shows dynamic stiffness data of rubber bush. The connection property is important factor when applying FBS method. If the dynamic stiffness is measured with expanded frequency range and the measured values are accurate, the FBS synthesized results are expected to be improved within the more expanded frequency range [3].

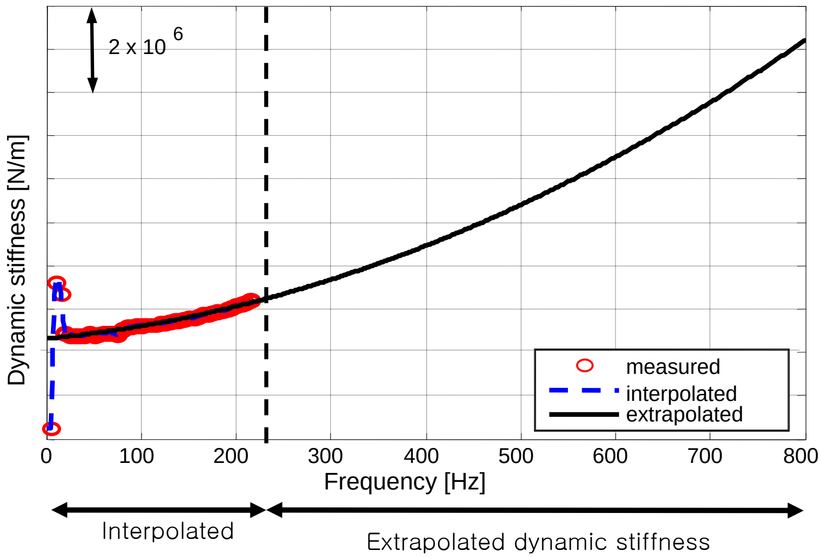

Figure 4 – Dynamic stiffness of rubber bush

Substructure Synthesis Results

The FBS synthesis results were validated by comparison with measured FRF data. Test based FBS solution is calculated with experimental models and hybrid FBS solution is calculated with experimental vehicle body and FE subframe model. Excitation direction is represented in Figure 2. The Figure 5 shows that FRF synthesis results are consistent with measured data within the frequency range of 0 ~ 400 Hz. Disagreements at higher frequency seem to be because of inaccurate dynamic stiffness values. At first the test based FBS method was applied on the assumption that the substructures were connected with rigid joint while actually the substructures are connected with rubber bush. These test based FBS results were poor than Figure 5 test based FBS results which were calculated with consideration of dynamic stiffness of rubber bush.

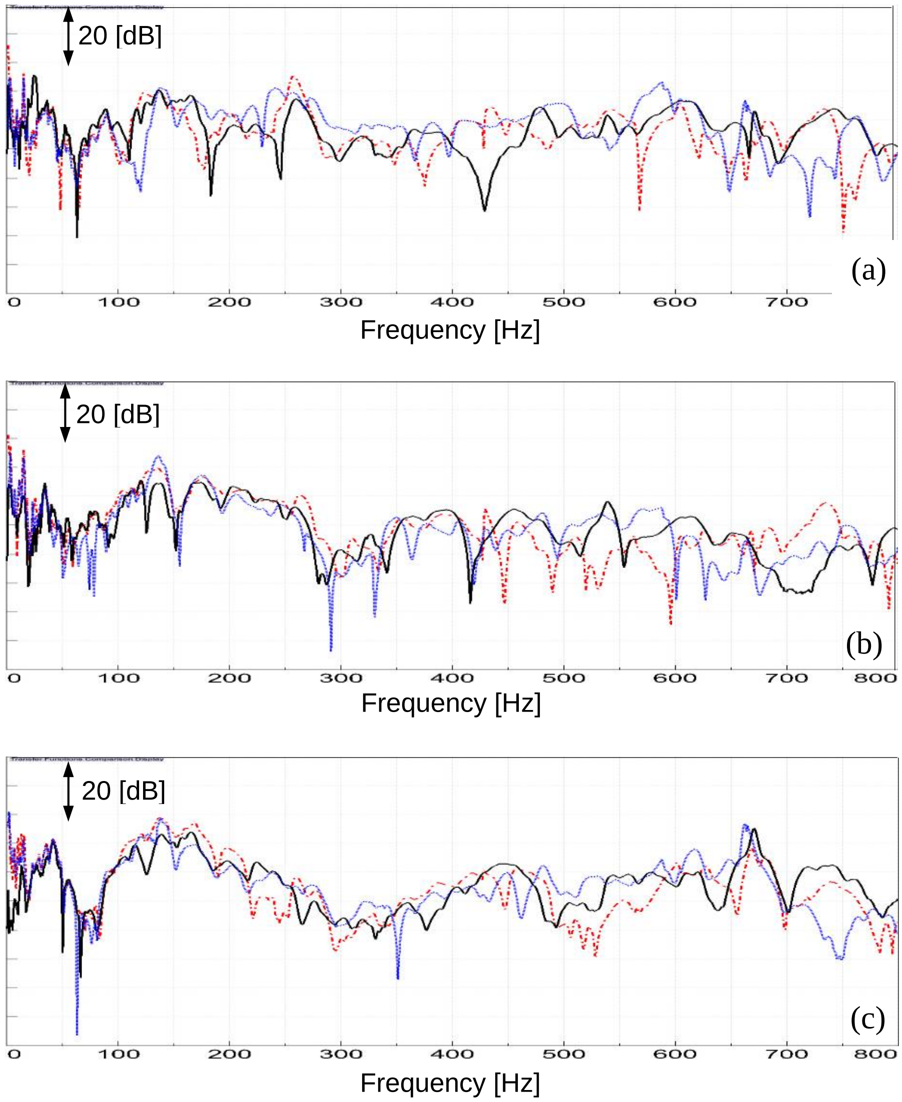

Figure 5 – The FBS synthesis results of front roll Mount (solid line : measured, dotted line : test based FBS solution, dashed dot line : hybrid FBS solution). (a) +X direction excitation, (b) +Y direction excitation, (c) +Z direction excitation

INTERIOR NOISE PREDICTION USING HYBRID FBS MODEL

Transfer path analysis (TPA) is the technique to identify contributions of selected paths to target response. However TPA was used to construct a simple interior noise prediction model in this paper. The identified forces and noise transfer functions which are obtained during process of TPA were used to construct the prediction model. Of course airborne noise and structure borne noise from other paths are not included in this model. Only four mounts system is considered as paths which transfer structure borne noise to vehicle cavity.

Transfer Path Analysis

Transfer path analysis is a tool which allows to assess the structure borne and airborne energy transfer ways from the source of power train system in an assembly to a given target location. This target can be acoustical pressure in a vehicle cavity during engine run-up, or the steering wheel vibration, at idle [5]. For this study, pressure in a vehicle cavity during run-up was selected as target.

Transfer path analysis is based on the combination of frequency response functions between the target point pressure and forces applied at the different possible energy transfer locations with forces that are active at these locations during operational conditions. This may be written as;

$$p = \sum \left[\frac{p}{F} \right] \times \{ F_{oper} \} \tag{1}$$

where p represents sound pressure at target point, p/F are vibro-acoustic transfer functions from the source to receiver point. This transfer function can be obtained by experimental way. F_{oper} are the operational forces at the interface of interest. These interface forces are usually difficult to measure directly. Therefore in order to identify operational forces, indirect methods are used. In this case matrix inversion method was used. This may be written as;

$$\{ F_{oper} \} = \left[\frac{a}{F} \right]^{-1} \{ a_{oper} \} \tag{2}$$

The matrix inversion method needs operational accelerations and transfer matrix which consists of transfer functions between interfaces of interest [6].

In case of selected vehicle, engine is supported with four mounts. Two of them are connected to body directly, and the others are connected to the subframe which is connected to body with six points. This four mounts were selected for target paths. Transfer matrices of p/F and a/F were measured by impact test at once, and operational accelerations and sound pressure were measured in laboratory by using dynamometer.

Interior Noise Prediction

Using the four mounts TPA model and hybrid FBS results, interior noise which is transferred through four mount paths could be predicted. TPA model consists of identified forces and noise transfer functions from target paths to the driver’s ear position. Among these four noise transfer functions, transfer functions from front roll mount to vehicle cavity were replaced with hybrid FBS results. As you know this hybrid FBS results were performed with subframe FE model and experimental vehicle body. The predicted result was compared with original TPA model in Figure 7.

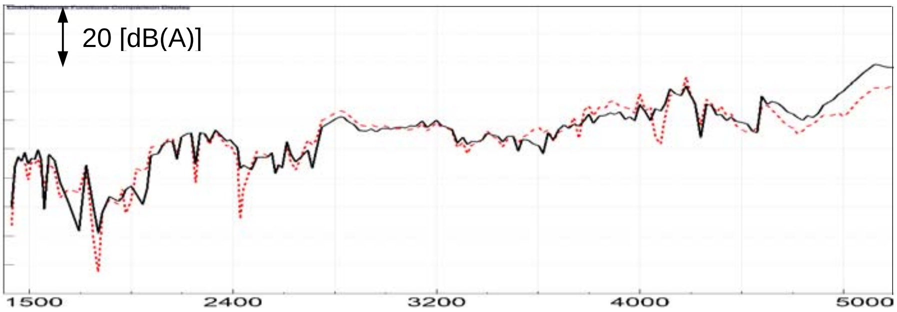

Figure 7 − Comparison of interior noise (solid line : calculated with TPA model, dotted line : predicted with hybrid FBS results)

The result shows very good agreement between experimental model and hybrid model. Because hybrid FBS results show good agreement with experimental noise transfer functions, this good result is a matter of course.

CONCLUSION

There are two important processes in applying hybrid FBS method. The one is obtaining the fine quality of test base FBS results. Because the test based FBS method and hybrid FBS method use same experimental substructure model, test based FBS results affect on hybrid FBS results. The other one is the correlation between FE model and experimental model. This is main process for reasonable prediction of system characteristics after substructure changed. Hybrid FBS results were added to the TPA model to make the hybrid model and the vehicle interior noise was predicted using the hybrid model. The prediction result showed very good agreement with experimental TPA result. Making these results to be more meaningful, some works should be accompanied. At first, to predict interior noise exactly, more major structure borne noise paths and air borne noise paths should be considered and by using optimization skills, modifying subframe FE model to reduce interior noise is needed.

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